■ Technical

Capacitors At High RF Power

Lloyd Butler VK5BR shares with us much useful knowledge about fixed capacitors in transmitting circuits.*

Introduction

In some of my articles on the Z Match Tuner, I referred to the use of high voltage fixed capacitors to achieve matching at 1.8 MHz. I discussed rated voltage but there are other factors which have to be considered in choosing a capacitor to operate in a high power RF circuit. I thought it would be useful to prepare a few notes on this subject.

Rated Current

Whilst the dominant impedance component in a capacitor is capacitive reactance, also included is a small resistance component caused by resistance in the electrode assembly and losses in the dielectric. When an AC voltage is applied across the capacitor plates, a reactive current flows, essentially equal to the applied voltage divided by the capacitive reactance. The point of interest is that heat is developed in the capacitor by this current passing through the resistance. As the reactance is inversely proportional to frequency, the current increases with frequency and hence the heat dissipation increases with frequency. Excessive rise in temperature caused by excessive heat can destroy the capacitor and a capacitor made for RF power applications, with high developed voltage, also has a maximum AC current rating.

At low frequencies, the limiting rating factor is the voltage across the capacitor plates. However, there is a frequency for a given capacitor above which the limiting factor is the current through it. Above this point, the voltage which can be applied must be lowered inversely with frequency so that the reactive current does not exceed the rated limit.

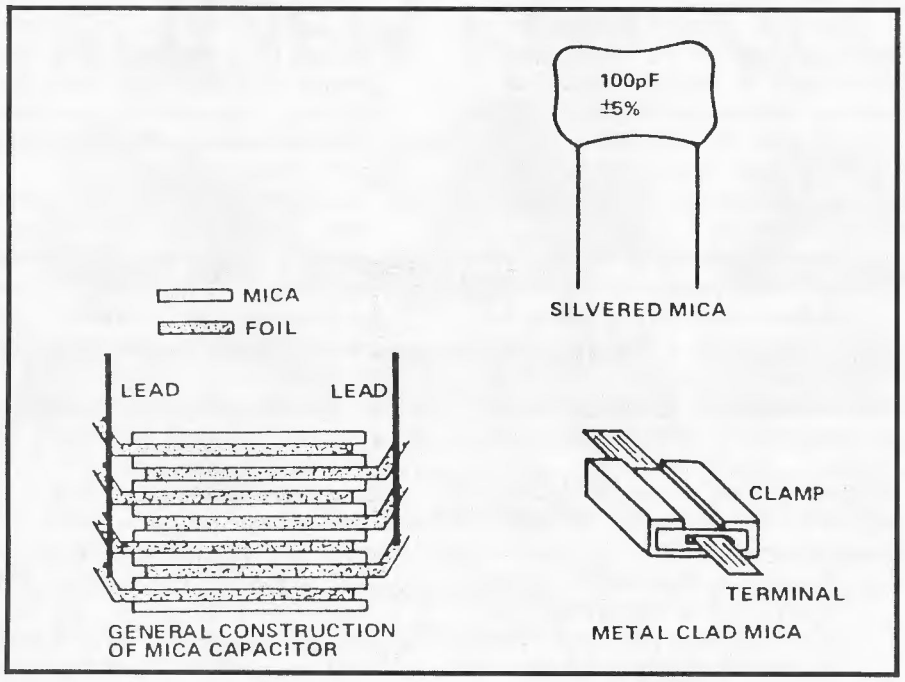

Figure 1 Mica Capacitors.

Let's take the typical case of our Z match at 1.8 MHz where a fixed capacitor of around 1000 pF is connected as part of the input capacitance and a fixed capacitor of 400 pF is connected across the coil. When the tuning unit is properly matched to load 50 ohms and the power is 400 watts, an RMS voltage of around 250 might be developed across the input capacitor and an RMS voltage of around 350 might be developed across the shunt capacitor. At 1.8 MHz, the 1000 pF capacitor has a reactance of 88 ohms and the 400 pF capacitor has a reactance of 220 ohms. The respective RMS currents are then worked out as 250/88 = 3 amps and 350/220 = 1.6 amps.

Allowing for the peak value of voltage and a 50% margin, we might seek a voltage rating of around 540 V for the input capacitor and around 750 V for the shunt capacitor with RMS current ratings of around 3 A and 2 A respectively.

Mica Capacitors

Muscovite mica is an excellent low loss dielectric material and mica dielectric capacitors have been around since the early days of radio. Mica capacitors have high insulation resistance, low power factor and are frequency and temperature stable. They perform well up to frequencies of 500 MHz and, made to an appropriate size, can handle large RF currents and high voltages. For many years they have been used in transmitting applications.

Basically, there are two types of mica capacitors. The stacked foil unit consists of alternate layers of metal foil electrodes separated with sheet mica insulators. These are sometimes marked "MS" for stacked mica. The silver mica type, sometimes marked "SM", have a silver electrode material screened on the mica stampings which form the electrodes. The silver mica type have very high stability and are highly recommended for use in oscillators and other critical applications requiring stable capacitance. However, they do not withstand high RF currents and for circuits where there are high RF voltages or currents, the stacked foil unit should be used.

High voltage mica capacitors are ideal for the RF power application but these days, it is difficult to buy a mica capacitor of any sort from the local electronic store. They seem to have disappeared from the catalogues, apparently superseded by capacitors using dielectrics of synthetic material. Furthermore the stores no longer seem to cater for high voltage or high power RF components of any sort. The source of supply is the amateur radio trading marts or electronic sales. All sorts of valuable junk changes hands — valuable because you can't buy it anywhere else.

High voltage mica capacitors specifically made for high RF power often have the current rating printed on their case together with the voltage rating. If there is nothing to define the current rating and there is voltage rating well above that required, the chances are that at the low frequency of 1.8 MHz, current will not be a problem.

Ceramic Capacitors

Whilst radio transmitters of early vintage used mica dielectric capacitors in their high power RF circuits, transmitters of more recent vintage have used ceramic dielectric capacitors specially made to withstand the high voltage and high currents inherent in the circuitry. These capacitors are somewhat larger than the common forms of ceramic capacitor and are invariably of disc or tubular construction. I have found an interesting introduction to these capacitors from a catalogue distributed by Unilator Technical Ceramics who manufacture ceramic capacitors. They refer not only to a voltage and current rating but also a reactive volt/amp (VAR) rating, the product of the two. The following paragraphs are extracted from their catalogue:

Power capacitors can be defined as capacitors suitable for radio frequency use with reactive powers in excess of 1 KVAR, 1 amp RMS and rated voltage above 700 volts peak.

The electrical performance is determined by the current and power ratings. These parameters are interdependent as specified by the equations:

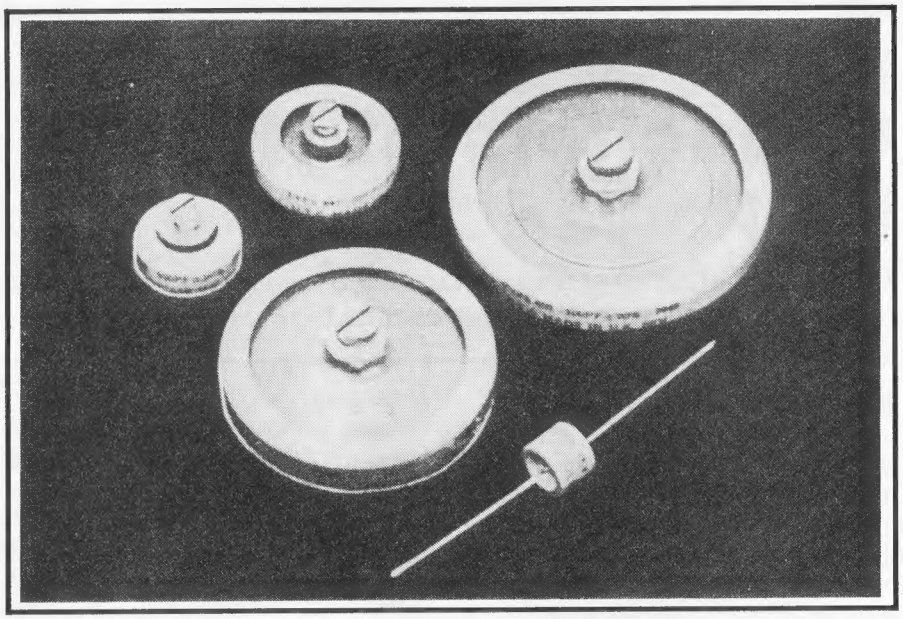

Figure 2 High voltage ceramic disc capacitors.

$$VA_R = V^2\, 2\pi f\, C - (1)$$

$$VA_R = \frac{I^2}{2\pi f\, C} - (2)$$

VA_R = Reactive Power
V = Voltage (volts)
I = Current (amps)
C = Capacitance (farads)
f = Frequency (Hz)

When a power capacitor is subjected to an RF load heat is generated in the dielectric due to internal losses and in the electrode system due to resistance heating. Depending on the applied power the temperature of the capacitor will rise until either:

(1) thermal stability is reached; or
(2) thermal runaway occurs resulting in destruction of the capacitor.

In practice, the maximum temperature of the capacitor should not exceed 95 degrees C. The performance is characterised by a typical reactive power versus frequency load curve as shown in figure 3. The curve can be split into three distinct zones:

(1) In Zone 1, the power rating is determined by the voltage rating of the capacitor. Below frequency f1 it is neither possible to operate the capacitors at maximum reactive power nor maximum current ratings.
(2) In Zone 2, the reactive power rating is limited by the temperature rise in the capacitor. Above f1, the maximum voltage that can be applied will decrease with frequency.
(3) In Zone 3, the reactive power rating is determined by the current rating of the capacitor. Above frequency f2, it is neither possible to operate the capacitor at maximum voltage nor maximum reactive power ratings.

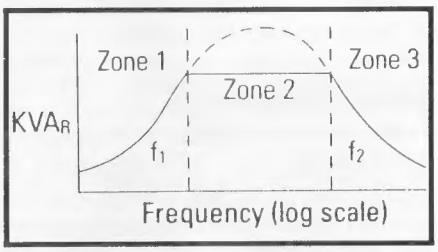

Figure 3 The reactive power versus frequency curve of the ceramic capacitor can be split into three distinct zones.

For any given capacitor ratings, the frequencies f1 and f2 can easily be calculated using equations (1) and (2).

Ratings are defined as follows:

(1) The voltage rating is either the peak AC, the peak AC+DC, or the DC voltage for which the capacitor is designed.
(2) The reactive power rating is such that capacitor temperature rise shall not exceed 45 degrees C

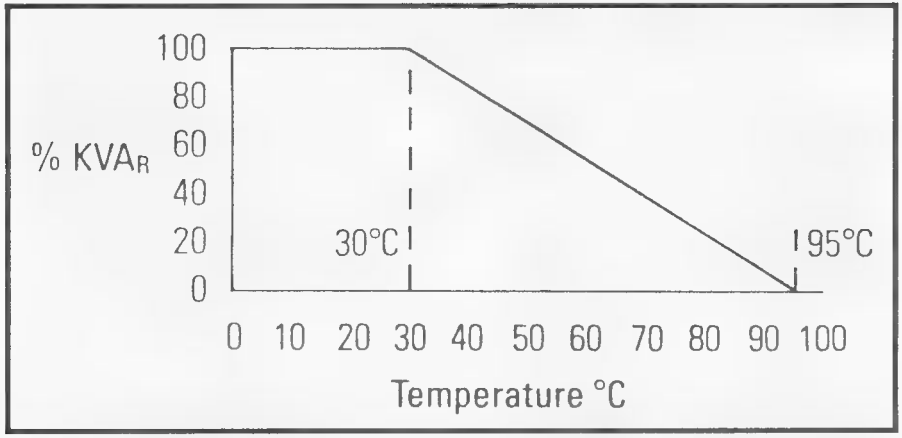

Figure 4 Reactive power rating of the ceramic capacitor must be decreased with increased temperature.

when operated at an ambient temperature of 30 degrees C.

(3) The current rating is the RMS current for which the capacitor is designed.

If capacitors are operated in an ambient temperature higher than 30 degrees C, then the reactive power rating must be reduced as shown in figure 4.

There is a lot more in the catalogue but I think those paragraphs provide an excellent introduction on how the ratings of high voltage/high power ceramic capacitors are used. I am out of touch these days with information concerning source of supply of these special capacitors but perhaps some of our readers might be able to supply *Amateur Radio* with that information.

Summary

This article has been prepared simply to alert the unwary that in selecting a fixed capacitor for high RF power, there is a little more to consider than just the voltage developed and the voltage rating of the capacitor. Capacitors have internal losses which amount to heat dissipated when alternating current is passed through them. Hence the rated current and the amount of heat dissipation must also be considered. Capacitors with low dielectric loss and ability to withstand a temperature rise are desirable.

Two types of capacitor suitable for high power RF have been identified as the stacked foil mica and the high voltage disc or tubular ceramic capacitor. Perhaps there are other suitable capacitors which someone else, with specialised component knowledge, might like to identify through the columns of *Amateur Radio*.

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